Development of Laser Interferometric Gravitational Wave Antenna(Abstracts of Doctral Dissertations)

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Development of Laser Interferometric Gravitational Wave Antenna

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Introduction

Recently gravitational wave detectors using a laser interferometer are making progress. This work is a study using the 10m prototype for laser interferometric gravitational wave antenna in ISAS[1].

Chap. 1. Gravitational Wave and its Detection

Since gravitational wave is very weak, its direct detection has never succeeded. Possible sources of gravitational radiation in the future detection of interferometer are supernovas or coalescing binaries. Provided of a detector with a sensitivity $h \sim 10^{-21}$, detectabilities of a few events per year are expected from Virgo Cluster(15Mpc). At present prototype antennas, which are 4 in the world, are working to realize an interferometer with such a sensitivity.

Chap. 2. 10m Interferometer

The 10m interferometer, which is based on a Michelson interferometer formed of two opposite mirrors in each arm to achieve long path length, is illuminated by a stabilized argon-ion laser. In each arm the laser beam is reflected by near and end mirrors with a beam number of 102. This multi-pass geometry is called optical delay-line. One of outgoing beam from the interferometer reaches the photo detector. The light is held to the dark fringe by a lock-in system, where the feedback signal would contain the gravitational wave signal.

Chap. 3. Noise behaviors in 10m Laser Interferometer

The fundamental limit of the sensitivity in an interferometer is given by the photon shot noise. Other noises must be reduced to less than the shot noise. The noise due to laser frequency fluctuation is proportional to path length difference in the two arms. Although simple Michelson interferometers can be easily adjusted so that the path length difference may disappear, it is difficult to satisfy the condition in the interferometers with the optical delay-line. In the case of our mirrors or mirrors for other prototypes, arm

[1]The Institute of Space and Astronautical Science.

length matching was impossible because of polishing limit of mirrors' surface, but it has been possible by new mirrors with difference of radius of curvature less than 5mm. By using these mirrors we obtained a small residual path length difference 1.1×10^{-3}m corresponding to CMRR[2] of 119dB for frequency noise. On the other hand over travel light scattered on the entrance hole of near mirrors becomes a large noise source. One of the method reducing the scattered light noise is phase modulation of incident laser beam so that the coherence between the main beam and the scattered light can be destroyed. Fig. 1 shows a improved sensitivity obtained by the reduction of scattered light noise.

Chap. 4. PSD[3] using Schnupp Method

At recycling losses in the E/O modules as Pockels cell can not be ignored. Schnupp suggested a method that the light is modulated before entering into the interferometer with different arm lengths and the signal feedback just to the mirrors' motion. For the first time We successfully verified the Schnupp method by using the arm with different number of beams in the delay-line and the new servo amplifier for dark fringe locking without the E/O modules.

Chap. 5. Long Term Continuous Operation

Long term operation of the 10m interferometer had done for 19 May～3 Jun 1992. The noise distributions of the interferometer were almost Gaussian since the scattered light noise was reduced. Namely we confirmed that there are not non-Gaussian component except the scattered light noise.

Chap. 6. Summary

In this study useful results were obtained. At present an upgrading of the interferometer to 100m is in progress. A goal of the sensitivity is $h\sim10^{-20}/\sqrt{\mathrm{Hz}}$ @1kHz. On the other hand a comparing the data of the long term operation with the data of GRO[4] is also being prepared.

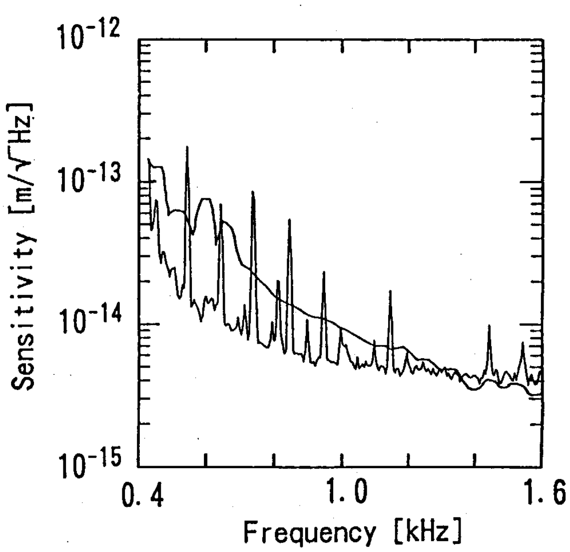

Fig. 1: Previous sensitivity(upper curve) and improved sensitivity(lower curve) in our interferometer.

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[2]Common Mode Rejection Ratio.
[3]Phase Sensitive Detection.
[4]Gamma Ray Observatory.